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and from its high place an observer might have seen more than 1000 kilometers round in all directions and would have overlooked a great part of Norway, Sweden, Russia, Germany, France, England and Scotland besides the whole of Denmark, Holland and Belgium.

THE REAL SCHOOL, ODDER, DENMARK,
1891, September 30.

OBSERVATIONS OF MARKINGS ON *JUPITER'S*
THIRD SATELLITE.

By J. M. SCHAEBERLE AND W. W. CAMPBELL.

Great interest has been shown by astronomers ever since the early days of the telescope in the question of the rotation periods of the satellites. The fact that our moon rotates on its axis once in a revolution about the earth has encouraged investigations to determine whether the law holds with the other satellites of the solar system.

As early as 1665, CASSINI* observed that when the satellites of *Jupiter* were in transit across the face of the planet, "he could see markings in exactly the positions where he knew the satellites to be, which proved that the markings were on the satellites themselves." Since these markings could not always be seen he inferred that the satellites rotated on their axis, but published no estimate of their periods. We now know that any attempt to see these markings by means of such rude telescopes as were at CASSINI'S disposal would prove futile.

Sir WILLIAM HERSCHEL† noticed that considerable changes occurred in the brightness of the satellites. During the years 1794-5-6 he made a number of estimates of their brightness when they were in different parts of their orbits, and found that the periodic variations of brightness were explained best by the theory that they rotate on their axes once in a revolution.

In 1796 SCHROETER‡ saw a dark marking on satellite III on three nights when the satellite was in the same part of its orbit,

* Director of the Paris Observatory. See *Histoire de l'Académie Royale des Sciences*. Tom. I, pp. 265-266.

† See *Philosophical Transactions*, Vol. 18, pp. 187-196.

‡ See *Astronomisches Jahrbuch*: 1800, pp. 169-170; 1801, p. 126.

and a marking on IV on two nights. A year later he wrote: "We have repeatedly seen dark spots on all the four satellites, even the two smallest, the first and second, with absolute certainty." From his observations he was led to conclude that "all the satellites without exception certainly rotate on their axis once in a revolution." However, the acute observer HERSCHEL observing at the same time "with abundant light and high powers," with the special purpose "to examine the nature and construction of the bodies of the satellites themselves," makes no mention of any markings.

On three occasions, in 1849 and 1860, DAWES* observed dark markings on the third satellite when it was in transit. His drawings agree remarkably well, and "render it probable that the same aspect of the satellite was turned toward the earth on all these occasions. But a larger number of observations was necessary in order to decide upon the rotation period.

SECCHI,† in 1855, observed several markings on III, from which he concluded that the satellite rotated on its axis in a very few hours. He says: "The difficulty of these observations is extreme; they require a very tranquil atmosphere, which is rare in this warm country [Rome]."

Photometric observations of the satellites by AUWERS and ENGLEMANN to some extent confirm HERSCHEL's results. But ENGLEMANN,‡ after reviewing all the known observations of III, both photometric and topographical, concludes that the observations are not yet sufficiently numerous and reliable to fix the rotation period of III.

Still later, in 1877-8, PICKERING§ measured the brightness of the satellites with great accuracy, and found no evidence of variability. He says: "It has been thought by many astronomers that the light of the satellites of *Jupiter* is variable. This view is not sustained by the present measurements."

The foregoing *résumé* is necessarily incomplete. Many of the observations omitted are of great interest, but, on the whole, they confirm the view that the question of the rotation periods of the satellites is still an open one.

The seeing at Mt. Hamilton on the night of August 24, 1891,

* See *Monthly Notices*, vol. XX, pp. 245-6.

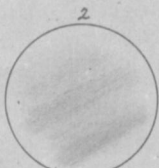
† See *Astronomische Nachrichten*, no. 1017.

‡ See his *Ueber die Helligkeitsverhältnisse der Jupiterstrabanten*.

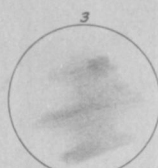
§ See *Annals Harvard Coll. Obs.*, vol. 11, p. 245.



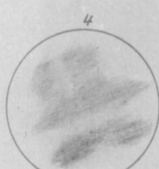
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Oct. 23^d 6^h 0^m
W.W.C.



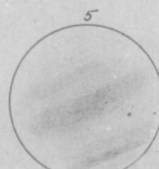
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Oct. 23^d 7^h 30^m
J.M.S.



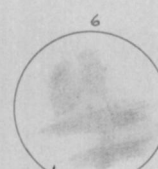
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Sept. 3^d 10^h 5^m
W.W.C.



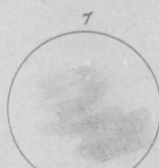
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Oct. 23^d 9^h 10^m
W.W.C.



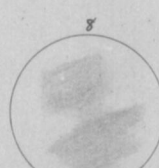
$\lambda = 25^\circ$
Sept. 3^d 10^h 10^m
J.M.S.



$\lambda = 68^\circ$
Oct. 24^d 5^h 55^m
W.W.C.



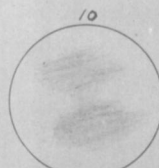
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Oct. 17^d 6^h 45^m
W.W.C.



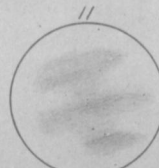
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Oct. 17^d 9^h 45^m
W.W.C.



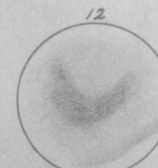
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Sept. 26^d 9^h 25^m
W.W.C.



$\lambda = 129^\circ$
Oct. 18^d 7^h 30^m
W.W.C.

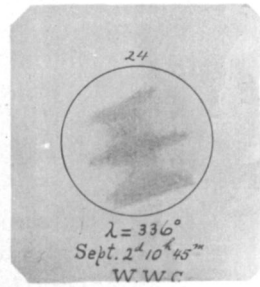
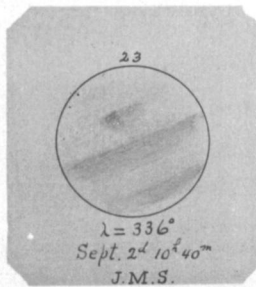
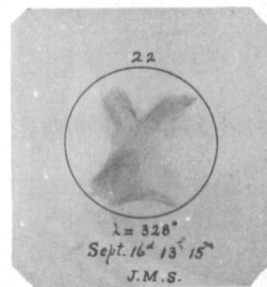
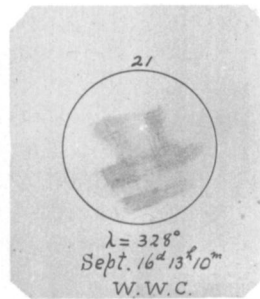
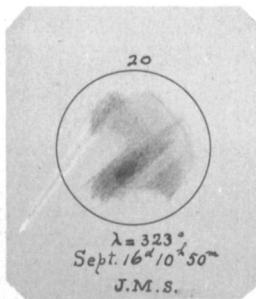
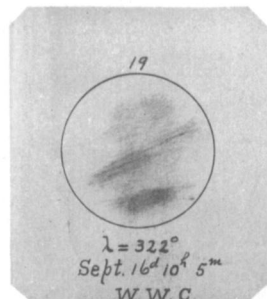
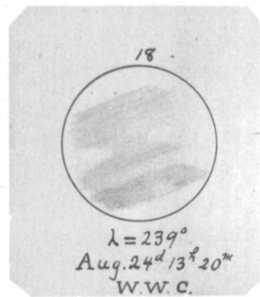
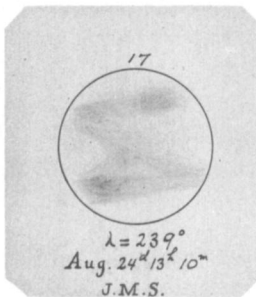
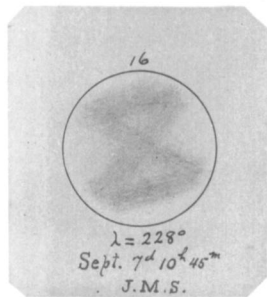
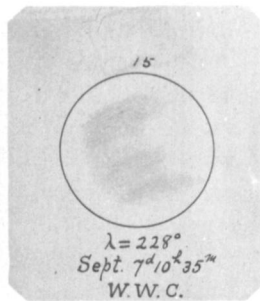
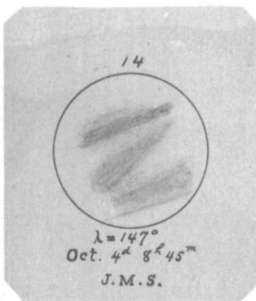
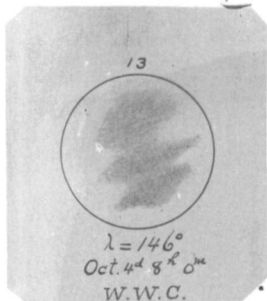


$\lambda = 129^\circ$
Sept. 5^d 10^h 35^m
W.W.C.



$\lambda = 131^\circ$
Sept. 5^d 11^h 20^m
J.M.S.

JUPITER'S THIRD SATELLITE.



JUPITER'S THIRD SATELLITE.

appearing to be unusually fine, the spectroscope attached to the 36-inch refractor was removed and the telescope directed to *Jupiter*. The seeing was perfect.

The surface of the planet was a mass of details, which could not be drawn in days. Turning to Satellite III, with a power of 2000, it was seen to be perfectly round. Some dark markings on its surface showed so plainly and certainly, that we independently made drawings of them. Two dark belts were well defined, as was also a lighter region between them. The northern polar region was much brighter than any other part of the surface. These markings remained practically unchanged under all powers from 700 to 2000 and for various positions of the eyes.

These drawings are reproduced in numbers 17 and 18 of the accompanying illustrations, together with those made later. All the drawings are arranged in the order of the positions of the satellite in its orbit, letting $\lambda = 0$ when the satellite is at inferior conjunction with respect to the earth. The recorded times are Pacific standard times. Horizontal lines on the drawings would represent the direction of *Jupiter's* equator.

Further observations of III are given below.

September 2, 3 and 5. Seeing, weight 2. Power 700. The drawings 23, 24, 3, 5, 11 and 12 made on these nights are of small weight. The north polar region was bright each night.

September 6. Seeing very fine. $\lambda = 184^\circ - 186^\circ$. The eclipse (reappearance of III) was observed with power 2000. The satellite occupied ten minutes in passing out of the shadow. In this interval its visible disk passed through all the phases from a thin segment to a full circle. The edge nearest to *Jupiter* was always fainter than the other edge, and the dividing lines between the umbra, penumbra and the fully illuminated portions were sharply defined. We were unable to see any markings on III.

September 7. Seeing, weight 2. Power 700. Markings difficult, north polar region bright. Drawings 15 and 16.

September 16. Seeing, weights 4 and 3. Powers 1000 and 700. The satellite was observed occasionally in the interval of three hours between the first and last drawings. The markings did not change appreciably, except to become more difficult. North polar region very bright. Drawings 19, 20, 21 and 22.

September 20. Seeing, weight 2. $\lambda = 160^\circ - 165^\circ$. No markings visible.

September 26. Seeing, weight 4. Power 1000. The mark-

ings were quite distinct. The north polar region not so bright as usual. [W. W. C. alone.] Drawing 9.

September 27. Seeing, weight 3. $\lambda = 155^\circ - 160^\circ$. No markings visible.

October 4. Seeing, weight 3. Power 700. Markings difficult, north polar region not so bright as usual. Drawings 13 and 14.

October 17. For drawing no. 7: seeing, weight 4. Powers 700 and 1000. Markings easy, north polar region bright. For drawing no. 8: seeing, weight 3. Power 700. Markings more difficult. [W. W. C. alone.]

October 18. Seeing, weight 2. Power 700. Markings very difficult and drawing of small weight. Both polar regions bright. Drawing 10. [W. W. C. alone.]

October 23. For drawing 1: seeing, weight 4. Powers 700 and 1000. Markings easy, and vertical channel in middle and south belts certainly seen. North polar region very bright, south polar region bright. [W. W. C.] For drawing 2: seeing, weight 2. Power 700. Markings difficult, north polar region very bright. [J. M. S.] For drawing 4: seeing, weights 3 and 4. Power 700. Markings easy, polar regions bright. I feel sure the markings have not changed appreciably in the interval of 3^h 20^m. [W. W. C.] At 11^h 50^m, seeing too poor to see markings.

October 24. Seeing, weight 3. Power 700. The markings easily seen, and during an interval of 2½ hours they did not change appreciably. The north polar region bright. Drawing 6. [W. W. C. alone.]

October 26. Seeing, weight 3. $\lambda = 172^\circ - 177^\circ$. Image steady. The surface apparently uniform, except the perimeter was bright by contrast.

Until this series of observations was completed we purposely avoided looking up the work of previous observers. We were not acquainted with the drawings of DAWES, SECCHI and others, nor with the details of the photometric observations of HERSCHEL, AUWERS, ENGELMANN and PICKERING. We likewise avoided making a study of our own drawings to see if they supported any theory. Moreover, each of us made his drawings independently of the other; several eye-pieces were generally used before a drawing was finished; the satellite was observed with the eyes in different positions; and the position angle of *Jupiter's* equator was indicated

on the drawings every night except the first. In spite of all these precautions the drawings are probably not free from personal errors.

For values of λ between 147° and 228° , that is when the satellite was in the part of its orbit furthest from the earth, we were unable to see markings clearly enough to draw them, although on four evenings [September 6, 20, 27; October 26] attempts were made to do so. It is probable that the markings on the hemispheres presented to us at those times were actually fainter than those seen at other parts of the orbit. Failure to see them could hardly be due to the nearness of the bright planet, for the markings when the satellite was nearly between the earth and *Jupiter* were apparently not affected by the proximity of the planet.

It is apparent from the drawings that the satellite is in general crossed by three dark belts, more or less broken, of which the upper (south) belt is the faintest. The estimated position angles of the belts (with reference to *Jupiter's* equator) vary from 15° to 40° , the average being about 30° . If the satellite has a motion of rotation, the persistency of the belts shows that the axis of rotation made at this time an *apparent* angle of about 30° with the axis of *Jupiter*. This is confirmed to some extent by the fact that the bright north polar cap was situated symmetrically with respect to the north belt (whose north edge it sharpens greatly by contrast).

That the period of rotation is a long one, follows from the observations of September 16 and October 23, when the satellite was observed for several hours without apparent motion of the markings. In no case was any motion observed in the course of an evening's observations.

With very few exceptions a comparison of the individual drawings shows that the satellite rotates on its axis once in a revolution around the planet, and therefore, like our moon, always presents the same face to its planet. This theory represents the observations much better than any other. The apparent exceptions can, for the most part, be attributed to poor seeing, and are, in fact, only such as must be expected in all observations of very delicate shadings of this kind. The angular diameter of the satellite, as seen from the earth, was always less than $2''$; and in drawing the small and faint markings which are only a few tenths of a second of arc in size, it could not be expected that different observers would agree exactly in the minor details. It might seem at first sight, for example, that the drawings 17 and

18, made under the most favorable circumstances, differ very materially from each other. Yet such is not the case. If the drawing 17 be placed upon 18 it will be found that the dark and light portions of the one sensibly coincide with those of the other, and that the difference is one of detail. The same is true of the apparently dissimilar drawings 21 and 22. Though several of the drawings are entitled to small weight on account of poor seeing, it appears that those made on the same evening agree well with each other.

The vertical channels in the upper (south) belt do not support the theory of equal rotation and revolution periods unless there are at least four such channels. This is probably the case. The channel in drawings 1 and 4 was plainly seen, and apparently did not move in an interval of $3^h 20^m$. Those drawn in 6 and 7 were difficult and somewhat uncertain. The channel in 17 and 18 was easy. The one in 19, 20, 21 and 22 was plainly visible and did not move during the interval of $3^h 10^m$.

The manner in which the dark markings terminate before reaching the edge of the disk suggests the presence of an atmosphere on the satellite. For, although the contrast due to the dark background of the sky tends to obliterate the markings near the limb, yet it can hardly account for the uniform brightness of the perimeter (excepting, of course, the bright south pole and the very bright north pole).

In the present unfavorable (far south) position of *Jupiter*, we are unable to see any definite markings on satellites I and II, except the bright regions on their limbs referred to in the preceding paper. But very accordant drawings of satellite IV, made by us on September 16, promise well for the determination of its rotation period by the same method when, in three or four years, *Jupiter* attains its greatest northern declination.

None of the observations were made with powers less than 700. With lower powers we found it difficult to distinguish between a real marking and an apparent one caused entirely by contrast. Indeed, it is not improbable that the existence of some of the markings on satellites I and II reported by observers using low powers is doubtful for this reason.

An observation of satellite III with the 36-inch equatorial, on Aug. 17, 1890 [by E. S. H. and W. W. C., see *Publ. A. S. P.*, vol. III, p. 272], showed a dark marking which in the interval of $1^h 45^m$ appeared to move perceptibly, thus indicating a short rota-

tion period for the satellite. It was then in the position $\lambda = 285^\circ$, a part of the orbit to which none of our drawings correspond. The sketches made then locate the marking in the heavy central and lower belts of the drawings 18, 19, 20, 21 and 22. The seeing was average; but it is possible that the low powers used—360 and 520—together with any change in the seeing in the interval of $1\frac{3}{4}$ hours between the sketches, would account for the apparent change of position of the markings. So far as this observation goes it is opposed to the theory of equal rotation and revolution periods, but neither of the observers of that night is disposed to lay any very great weight upon it.

While the foregoing observations do not definitely decide the question of the rotation period of the third satellite, yet they very strongly support the theory that the satellite rotates on its axis once in a revolution about the planet.

The same conclusion with respect to the *first* satellite follows from our observations of this year. (See *Publications A. S. P.*, vol. III, p. 357.)

[The satellites of *Jupiter* were frequently examined during the oppositions of 1889 and 1890 and all the observers were satisfied that markings existed on some of them. The planet was, however, unfavorably situated as to altitude, so that no observations of special importance were made in those years.]